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IONS OF EXTRA-TERRESTRIAL ORIGIN IN THE
EARTH'S IONOSPHERE

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IONS OF EXTRA-TERRESTRIAL ORIGIN IN THE
EARTH'S IONOSPHERE *

(Iony vnezemnogo proiskhozhdeniya v iono-
sfere Zemli)

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by V. G. ISTOMIN

Measurements of the mass spectrum of positive ions by sounding rockets and with the help of the third artificial satellite were made to define the chemical composition of the main ion components which are responsible for the existence of the daytime Earth's ionosphere, and to study the variations with altitude of the composition of these main constituents in the E-, F₁- and F₂-regions. Nowadays, the necessary experimental data may be considered as obtained [1 — 3]. Considerable advances have been also gained in their interpretation, namely, the selection of possible photochemical and ion-exchange reactions, which can explain the observed ion composition [4, 5].

However, some rocket measurements detected ions, whose existence in the oxygen-nitrogen Earth's ionosphere requires further explanation as to their origin and the nature of the possible ionizing agents. These results, only partially published to-date, are presented below. (See reference [6]).

* This paper was also presented at the Washington Third Space Science Symposium in May 1962, of which the preprint called for re-writing.

METHOD OF MEASUREMENTS

The method of ion composition measurements by mass-spectrometer installed in rockets [1 - 3], as well as by radiofrequency mass-spectrometer in its various forms [7, 8], are well known and need no further detailed description, so that only the main peculiarities are worth mentioning.

To gain a maximum possible precision the equipment for measurements was installed in a container isolated from the rocket.

Inasmuch as the container's ejection takes place at 65 to 70 km altitude, its velocity relative to the rocket being of the order of $1 \text{ m} \cdot \text{sec}^{-1}$, it remains nearly all the time during the ascent period in the uncontaminated region of the atmosphere, at a distance from the rocket exceeding several times the molecules' mean free path. This is illustrated in the following Table:

Altitude, km	"Container-Rocket" Distance Ratio to the Mean Free Path
100	30
120	11
140	8
160	5
180	3.7
200	3
210	2.7

The radio-frequency mass-spectrometer analyzer consists of a tube, open at one end, with a set of plane-parallel grids inside it. It operates according to the principle of ion separation in axial

electric fields. One of the first such devices was proposed by Bennett [9]. The required alternating and fixed potentials are fed to the grids of the tube. The analyzer is installed on the container's surface, as is shown in Fig.1.

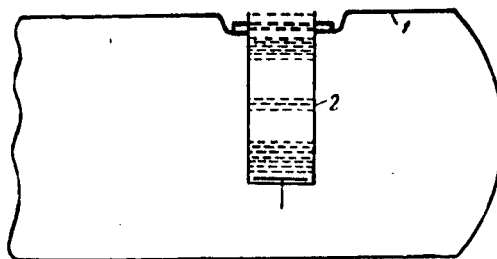


Fig.1. Scheme showing the installation of a radiofrequency mass-spectrometer's analyzer on the surface of the container.
1 — surface of the container; 2 — analyzer

Fig.2 shows the exterior appearance and the dimensions of the radiofrequency mass-spectrometer used in the launching of the sounding rocket on 15 June 1960.

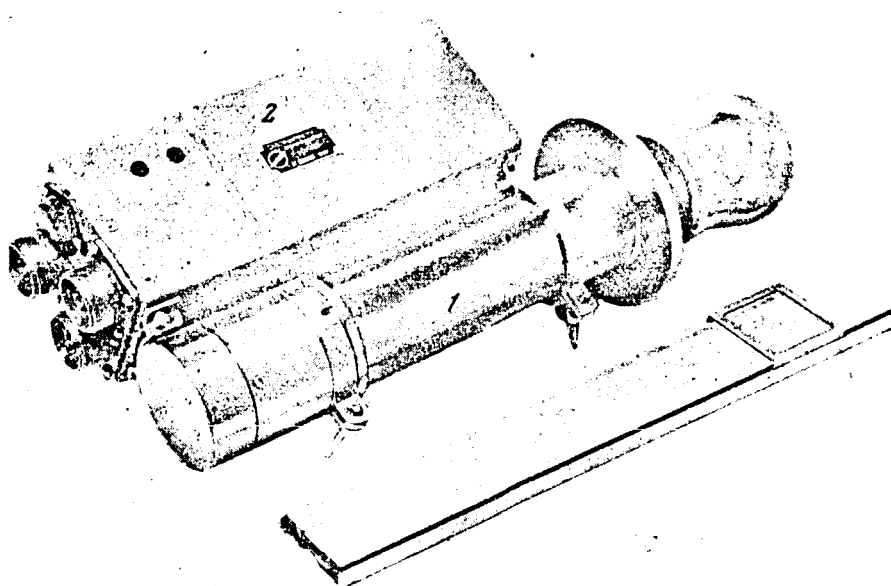


Fig.2.- 1 — analyzer; 2 — radiotechnical block

The ionic current of the mass-spectrometer's collector, amplified to the desired magnitude, is telemetered to the ground by a multi-channel high-speed sampling rate system. The recording of the ionic current as a function of time constitutes a series of periodically-recurring "peaks", everyone of which corresponding to the ions of a specific mass. (It is assumed that every ion carries a single elementary charge). The distance between the beginning of the mass spectrum and the peak is the measure of its mass number, and the peak's amplitude is nearly proportional to the concentration of ions of the given mass (with a precision to possible effects of mass discrimination in the drawing field region and in the analyzer itself).

R E S U L T S

During the sounding rocket firing which took place in the morning of June 15, 1960, in the middle latitudes of the European SSR, when the height of the Sun was 15° , the usual for these 100 to 200 km altitudes NO^+ and O_2^+ ions were registered simultaneously with magnesium ions- Mg^+ . A higher-sensitivity radiofrequency mass spectrometer (Fig.2) was used in this experiment for the first time.

Somewhat more than 100 spectra were obtained in the 92 to 206 km altitude range, five of which having peaks with mass numbers 24 and 26, while three of them were obtained in the ascending branch of the trajectory, and two — in the descending one. These and also some of the preceding and subsequent spectra are shown in Fig.3. A good agreement in the altitude registration of peaks with $M = 24$ and $M = 26$ is observed respectively in the ascending and descending branches of the trajectory.

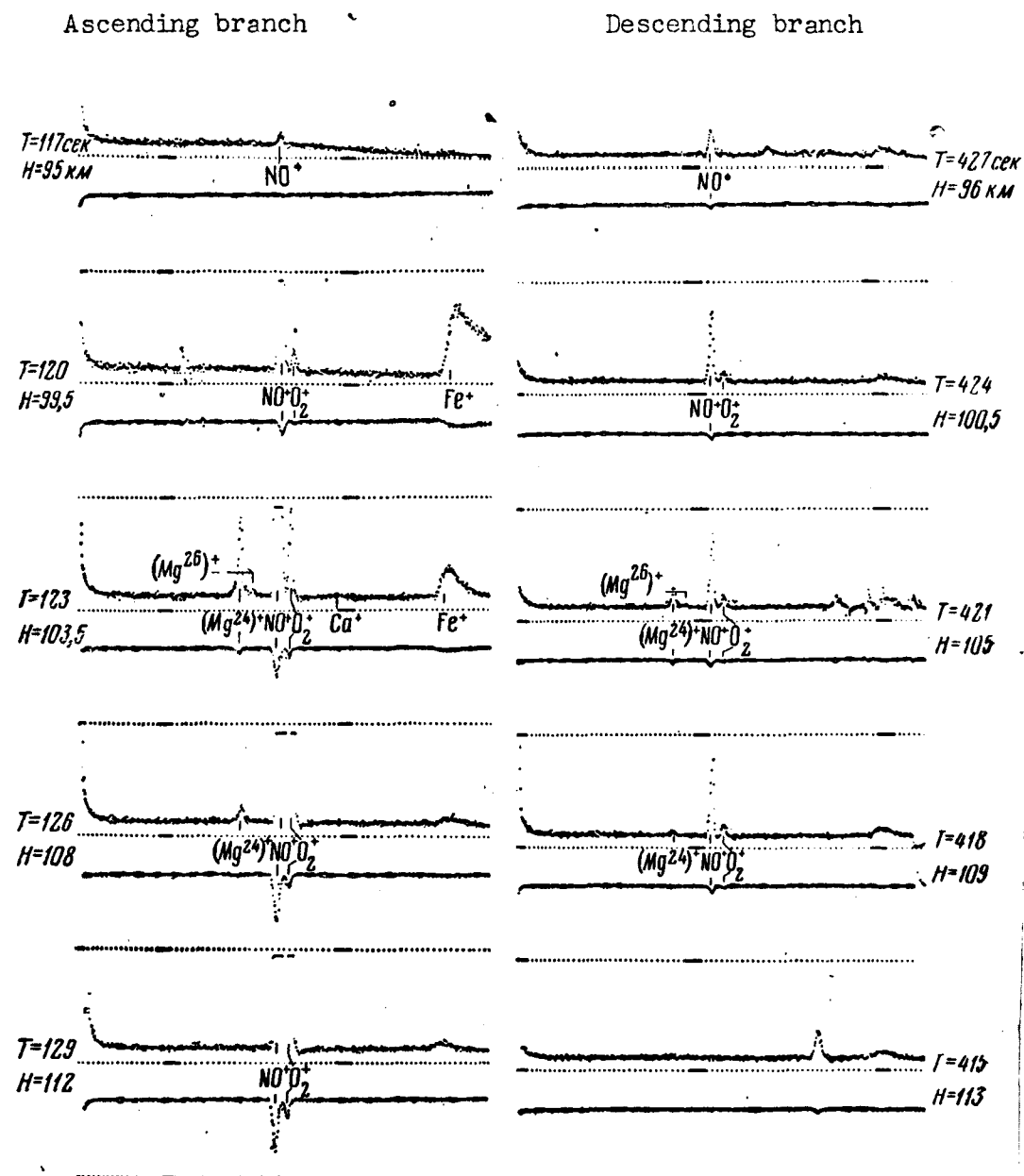


Fig.3. Mass spectra of positive ions, obtained at rocket launching in the morning of June 15, 1960.

All ion components are marked by appropriate chemical symbols. The peaks of spectra of the descending trajectory, not designated by the symbols, belong to contamination ions.

Thus, spectra with maximum amplitude of these peaks were respectively obtained at 103.5 and 105 km altitudes. Taking into account that the period of mass scanning was about 3 sec., which in the given case is equivalent to a ~ 4 km altitude variation, such coincidence is more than satisfactory.

The element with a mass number $M = 24$ is magnesium. Aside from the Mg^{24} isotope, there also exist Mg^{25} and Mg^{26} isotopes, their relative abundance being respectively 78.6, 10.1 and 11.3 percent [10]. If the recorded ions with $M = 24$ and 26 are magnesium ions, the ratio of peaks' amplitudes $\frac{i_{24}}{i_{26}}$ must be equal to 7. The results of peaks' amplitude measurements are given in the following Table:

Time	Height	Relative Intensity		Concentration
$T, \text{ sec}$	$H, \text{ km}$	i_{24}/i_{26}	$\frac{i_{\text{Mg}^+}}{i_{\text{NO}^+} + i_{\text{O}_2^+} + i_{\text{Mg}^+}}$	$[\text{Mg}^+], \text{ cm}^{-3}$
120	99,5	—	$< 0,01$	< 400
123	103,5	$10 \pm 2,4$	$0,17 \pm 0,01$	13 600
126	108,0	9 ± 6	$0,02 \pm 0,01$	1 600
129	112,0	—	$< 0,002$	< 160
135	120,0	—	$0,005 \pm 0,001$	400
418	109,0	—	$0,03 \pm 0,016$	2 400
421	105,0	9 ± 5	$0,17 \pm 0,02$	13 600
424	100,5	—	$< 0,02$	$< 1 600$
Summary i_{24}/i_{26}		$9,3 \pm 5$		

Taking into account the possible systematic errors obtained from the magnitudes brought out in the above Table, the mean value of $\frac{i_{24}}{i_{26}} = 9.3 \pm 5$ must be recognized as corroborating the assumed identity of ions with $M=24$ and $M=26$ with magnesium ions. The Mg^{25} isotope is not visible on account of insufficient resolution. The presence of some

Mean
value

dissymmetry at the basic points of the Mg^{24} peak points to its existence. (see the spectrum for $T = 123$ seconds, Fig. 3).

With independent measurements of electron concentration in the atmosphere on hand, one can compute the absolute concentrations of positive ions registered by the mass spectrometer using the correlation

$$[M_1^+] = i_{M_1^+} \cdot n_e / \sum i_{M_k^+}$$

where n_e is the electron concentration in the atmosphere, and M_k^+ — the ions registered by the mass spectrometer.

The maximum value of the intensity ratio of magnesium ionic peaks to the aggregate intensity of all registered ionospheric components constitutes

$$i_{\text{Mg}^+} / (i_{\text{No}^+} + i_{\text{O}_2^+} + i_{\text{Mg}^+}) = 0.17.$$

The electron concentration in the given rocket firing was determined with the aid of a rocketborn UHF dispersion interferometer similar to that described in [12]. At altitudes from 100 to 110 km $n_e = 8 \cdot 10^4 \text{ cm}^{-3}$. hence the value of the magnesium ions' maximum concentration at the 103.5 to 105 km height will be $[\text{Mg}^+] = 1.36 \cdot 10^4 \text{ cm}^{-3}$.

Fig. 4 shows the recorded magnesium ion concentration variation with altitude and the possible profile of the layer. Assuming the half-width of the layer equal to 5 km, the total number of ions in the unit column will be equal to $N_{\text{Mg}^+} \approx 7 \cdot 10^9 \text{ cm}^{-2}$. It is natural that that the given layer profile can only be considered as representing conditionally the real pattern of Mg^+ ion distribution, because of the small number of experimental points (spectra).

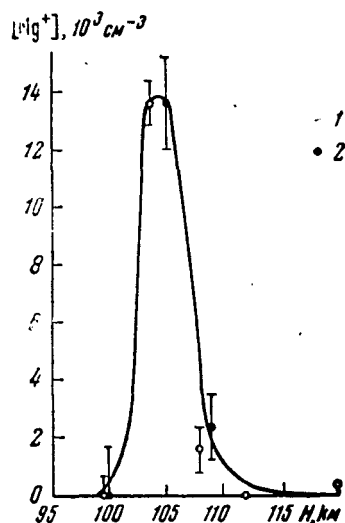


Fig. 4. Concentration of Mg ions in the atmosphere as a function of the height H: 1 — measurements in the ascending branch of the trajectory; 2 — measurements in its descending branch; the smooth line indicates the possible ion Mg⁺ profile

Attention should also be drawn to the reliable ion Mg⁺ registration in the spectrum obtained during that flight at 120 km altitude (Fig. 5), for in the previous and subsequent spectra the $M = 24$ peak was absent. It may thus be said that there exist two maxima of magnesium ion concentration at altitudes of ~ 104 km and ~ 120 km.

In the spectrum for $T = 135$ sec (120 km) there is a peak with $M = 28$, which is absent in all the preceding and in many of the ensuing spectra. Its possible identification will be discussed later.

An appreciable peak of ion current with $M = 40$ may be seen at attentive study of the spectrum for $T = 123$ sec, obtained during ascent at 103.5 km altitude. Since peak with $M = 40$ is absent in the preceding and following spectra, it is natural to link its registration with a simultaneous appearance of Mg⁺ ions, and ascribe it to the presence in the same layer of calcium Ca⁺ ions. The relative prevalence of the Ca⁴⁰ isotope makes up 97 percent. Ar⁴⁰ is another stable isotope with a considerable relative prevalence. However, such an identification cannot be made acceptable on account of a series of considerations. To the contrary, by the strength of available data on the presence in the twilight sky spectrum of ionized Ca II lines [13, 14], the identification of the peak with $M = 40^+$ with Ca⁺ ions is doubtless. The Ca⁺ ion peak cannot be traced in the other

spectra of Fig. 3, for its amplitude there must be less than the threshold value of observability.

At last, there is one more important peculiarity in the spectra obtained at rocket launching on 15 June 1960. As a result of transient processes of mass-scanning at the end of each spectrum, a small "ridge" of ion current, not having anything to do with the presence of any sort of ions, is usually registered. The mass range of the MX-6403 device utilized in the ion analysis regime ends in the $M = 56$ region, and this mass cannot be normally reproduced in the spectrum. Nevertheless, the ionic currents are abnormally high at the end of the scanning, at least in two spectra of the ascending branch, at altitudes corresponding to ion Mg^+ appearance, say at 100 to 105 km. The same is observed in the descending branch at the same altitudes. The only possible explanation of the peculiarities mentioned is the assumption that there are in the given altitude range, alongside with clearly registered Mg^+ , NO^+ , O_2^+ and Ca^+ ions, great quantities of ions with a mass number $M = 56$.

The only stable isotope with $M = 56$ is the Fe^{56} isotope (91.7%), characterized by a great relative abundance. The concentration of Fe^+ ions in the layer maximum is, as estimates show, of the order of magnitude close to ion Mg^+ concentration, i.e. $[Fe^+] \approx 1.5 \cdot 10^4 \text{ cm}^{-3}$ at 101 km altitude.

The detection of metal ions during the latest of experiments carried out, served as a boost toward a more elaborate study of the results obtained earlier from telemetric readings at similar rocket launchings, and more particularly in the 100 to 120 km altitude range.

It is necessary to take into account the fact that the method used was not especially intended and was not anticipating relatively "fine-structural" investigations of ion composition variation as a function of height. Thus, the lack of any definite container's orientation after its separation from the rocket constituted a limiting factor. At 100 km (with a ceiling near 200 km) the container flies at the $1.5 \text{ km} \cdot \text{sec}^{-1}$ speed while the mean thermal velocity of the ion with $M = 30$ at a $T = 300^\circ \text{K}$ temperature is about $0.4 \text{ km} \cdot \text{sec}^{-1}$. Under such conditions, the mass spectrometer's sensitivity depends upon the orientation relative to the vector velocity of the tube's inlet opening. By the strength of the above, measurements are not always possible in the 100—120 km altitude range, where thin layers, non-typical for the nitrogen-oxygen atmosphere of metal ions, are known to exist, for the container's orientation might not be optimum. The comparatively large period of mass-scanning also was a hindering factor for ion thin layer detection. The mass-scanning period of the RMS-I device [7], which was used in 1957-1958 measurements, was 1.7 sec, which corresponds to about 2.5 km altitude variation. The mass-scanning periods of mass spectrometers utilized in subsequent experiments (1959-1960), was of the order of 3 sec, corresponding to $\Delta H \sim 4 \text{ km}$. At times, there were limiting factors, such as an insufficient sensitivity of the device or a high noise level.

Nevertheless, ion peaks with $M = 56$, identified with Fe^+ ions, were also detected in the course of the re-examination of mass spectrum readings, obtained at the daytime geophysical rocket launching on 2 August 1958, when the Sun was 36° high, particularly in two of them, corresponding

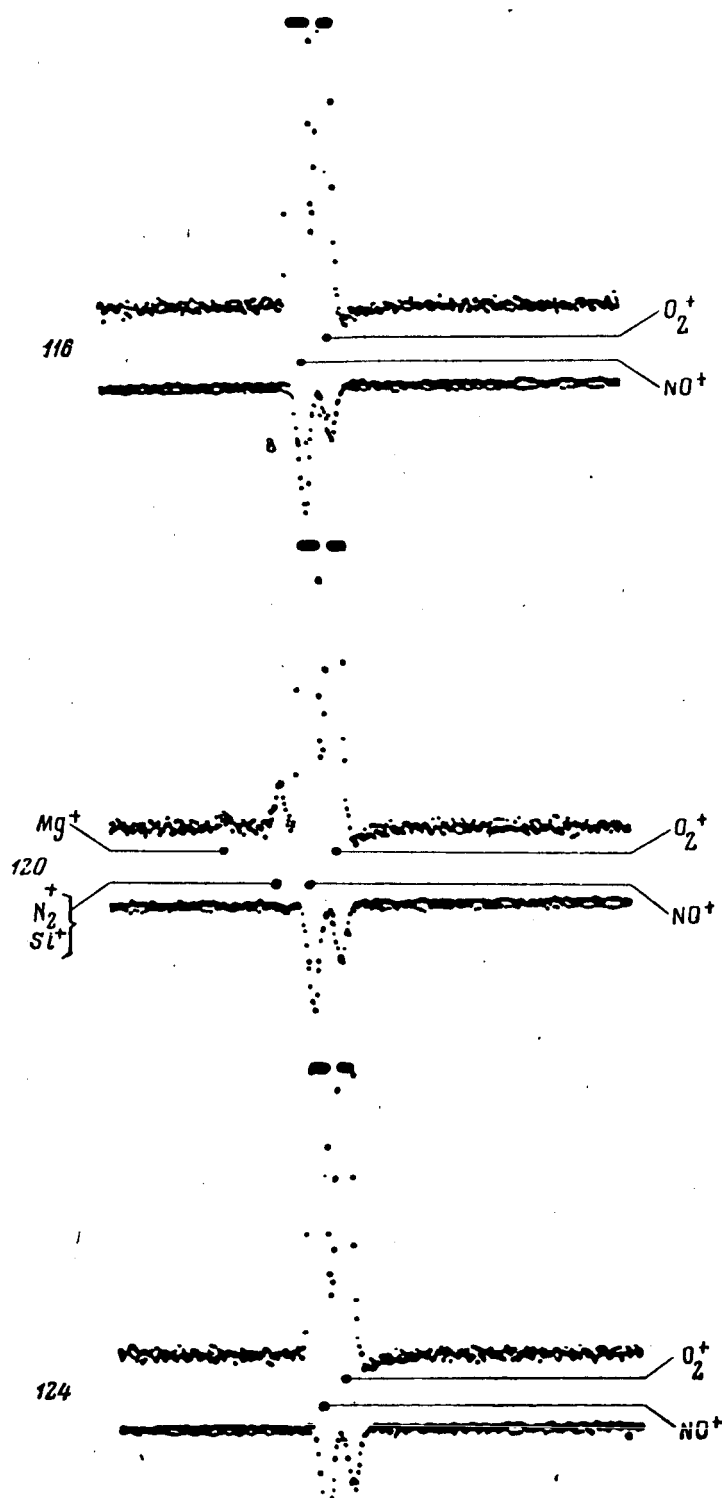


Fig. 5. Mass spectra of positive ions obtained at the morning launching of 15 June 1960

Altitude in km is shown at left. Spectra indicate the existence of a complementary layer of ions with $M = 24$ (Mg^+) and $M = 28$ (Si^+ or N_2^+) at the 120 km altitude.

to about 105 km altitude in the ascending as well as in the descending branches. The possible error in mass number determination during this experiment in no case exceeds ± 1 a.e.m., inasmuch as the device's range extended to $M = 62$.

As may be seen from the comparison of ion Fe^+ peak amplitudes with the "normal" for the given altitude NO^+ and O_2^+ ions (Fig. 6), the concentration of iron ions constitutes a notable part of the total ionic (electron) concentration. No independent measurements of electron concentration were carried out at rocket launching on August 2, 1958. Thus the possible estimates appear to be less reliable. If we take advantage of the results of n_e measurements effected during the daytime launching of the geophysical rocket of August 27, 1958 [15], when the Sun's height was 15° , and under conditions close to August 2 measurements, we obtain for the registered ion concentration the value $[\text{Fe}^+] = 1.2 \cdot 10^4 \text{ cm}^{-3}$.

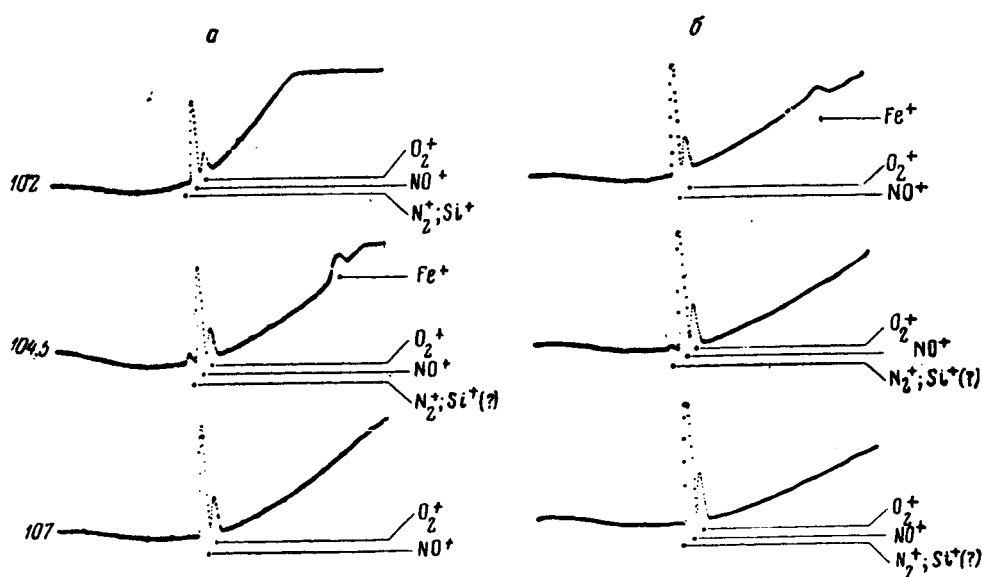


Fig. 6 Mass spectra of positive ions obtained during the daytime rocket launching on August 2, 1958.

a — ascending branch b — descending branch; altitudes in km, at left. Spectra indicate the presence of ions with $M = 56$ (Fe^+) and $M = 28$ (Si or N_2^+).

From the spectra brought out in Fig. 6, it may be seen that ions with $M = 28$ are registered in the same limited altitude range where ions Fe^+ have been detected. Their most natural identification with molecular nitrogen ions N_2^+ is not the only possible one*). Silicon is the element with $M = 28$, and such an identification seems to be in harmony with the above-expounded results. The estimate of the maximum concentration of ions with $M = 28$ according to spectra indicated in Fig. 6 leads to the magnitude $7.5 \cdot 10^3 \text{ cm}^{-3}$.

If we identify the mass $M = 28$ with N_2^+ ions, we shall have to admit that their occurrence in the E-region of the ionosphere at 105 km is unexpected and requires a special explanation despite the fact that nitrogen is the main constituent of the atmosphere at those altitudes. The question of causes of molecular nitrogen ionization in the terrestrial atmosphere has not yet been finally solved to-date. In the light of ideas expounded in reference [16] and of new data on line $\text{He } \lambda 304$ absorption [17], according to which this emission, capable of ionizing the nitrogen molecule, is absorbed in the 210 to 150 km altitude range, the Danilov's deductions, explaining the molecular nitrogen ionization by charge-exchange reactions with atomic nitrogen ions: $\text{N}_2 + \text{N}^+ \rightarrow \text{N}_2^+ + \text{N}$, appear to be quite convincing. This must doubtless be valid for the altitude region of 250 km and above. At the same time it is obvious, that the appearance of N ions in the E-region, at 100 to 120 km heights, can neither be ascribed to the direct N_2 photoionization (no corresponding emission quanta), nor to charge-exchange reaction (lack of N^+ ions, see [18]).

*) The identification of $M=28$ with Fe^{++} ions is formally possible, though hardly probable, inasmuch as the mass spectrometer divides ions according to
(.. see next page)

Therefore, the occurrence of ions with $M = 28$ in the E-region must serve as an indication of the existence of some other N_2 ionization processes, or else, these ions must be identified with silicon ions Si^+ . Such identification is, as was already mentioned, in harmony with the detection of Mg^+ , Ca^+ , and Fe^+ ions. It is well known that magnesium, silicon and iron (alongside with oxygen) precisely are the elements prevailing in stone meteorites.

The recorded ratio of magnesium to calcium ion concentrations

$$\frac{[Mg^+]}{[Ca^+]} = 25 \pm 8$$

is close to the ratio of the number of their atoms in meteorites: $[19]: = 15$. This is understandable from the viewpoint of the meteor hypothesis on the origin of the detected ions, for the atoms' Mg and Ca ionization (whether photoionization or ionization at their interaction with atmospheric molecules), as well as the recombination of the formed Mg^+ and Ca^+ ions, must take place in an identical manner. Because of the analogy of these metals' physico-chemical properties, the constants of ionization and recombination processes must be very close.

Estimates of the total number of Ca^+ ions in the unit column, made according to the obtained spectra ($[Ca^+] \approx 540 \text{ cm}^{-3}$; $N_{Ca^+} = 3 \cdot 10^8 \text{ cm}^{-2}$), agree well with the estimates made according to the intensity of the twilight sky glow of CaII lines: $N_{Ca^+} \approx 5 \cdot 10^8 \text{ cm}^{-2}$ [13]. The results of the work [13] are entirely comparable, since they were obtained in the course of the same month of June, during a period of daytime meteor shower activity ζ -Perseides and Arietides.

*)..cont'd from page 13: ... the ratio of their mass to the charge, and singly-charged ions with $M = 28$ cannot be separated from doubly-ionized particles with $M = 56$. For doublet $^{56}Fe^{++}$ — $^{14}N^+$ separation a high resolution is necessary.

The altitudes of "non-typical" metal ions for the terrestrial atmosphere are specific for meteor phenomena: they lose their cosmic velocities and vaporize fully or partially precisely in the 100 to 120 km altitude range, and this means that they make an optimum contribution from both, the energy viewpoint, and that of the quantity of matter entering the atmosphere, all this being true for the tiniest of all meteor particles vaporizing in the atmosphere.

Inasmuch as it is well known that lines of ionized iron, magnesium, calcium and silicon are observed in meteor spectra [21], there is little doubt about the substantial part played by the ionization mechanism of fast-flying meteor matter atoms at their non-elastic collisions with the molecules of the atmosphere. It is natural that daytime processes of neutral Ca, Mg, Fe and Si atoms' photoionization by solar ultraviolet radiation may take place alongside with it. (see [22]).

The above-presented results serve as a corroboration of the hypothesis by Nicolet [22] about the leading role of meteors in the night ionization of the E-region. The altitudes of the detected layers coincide precisely with the heights of the night E-layer, determined by radio-observations (100 to 105 km, see [22]), while ion concentrations of metals are of the same order of magnitude as the night values of the electron concentration in the E-region ($\sim 10^4 \text{ cm}^{-3}$).

It seems probable, that with improvement of the method (at the same or a somewhat greater resolving power) the ion mass spectrum analysis method in the E-region may be applied for the determination of meteors' chemical composition, and particularly of those not reaching the Earth

and therefore not susceptible of being analyzed by other methods.
One may hope in particular to obtain information on the diversity of
particle composition in meteor streams and in sporadic meteors.

***** THE END *****

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